



# **Pbar Acceleration in MI using 2.5 MHz ( $h=28$ ) and 53 MHz ( $h=588$ ) rf Systems**

**Chandra Bhat,**

Vincent Wu, Brian Chase, Keith Meisner,  
Joe Dey and John Reid

**Temple Review**

January 21, 2004



Our thanks are due to

- Dave Capista
- Ioanis Kourbanis
- Jim MacLachlan
- Dave Wildman
- Many Individuals in the MI/RF Group
- Operation group



- Why do we need a new pbar acceleration scheme in MI?
- Project Goal
- pbar Acceleration using 2.5 MHz ( $h=28$ ) and 53 MHz ( $h=588$ ) rf systems
  - MI Ramp
  - Simulations
- HLRF and LLRF Specifications
- HLRF and LLRF Feasibility and recent improvements
- Beam Studies :
  - Status
  - Data Analysis
- Future Plans
- Reliability issues

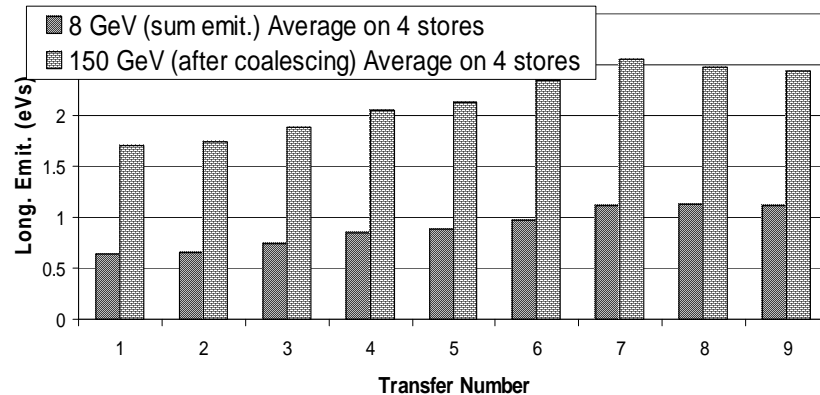


# Why do we need a new scheme for pbar acceleration?

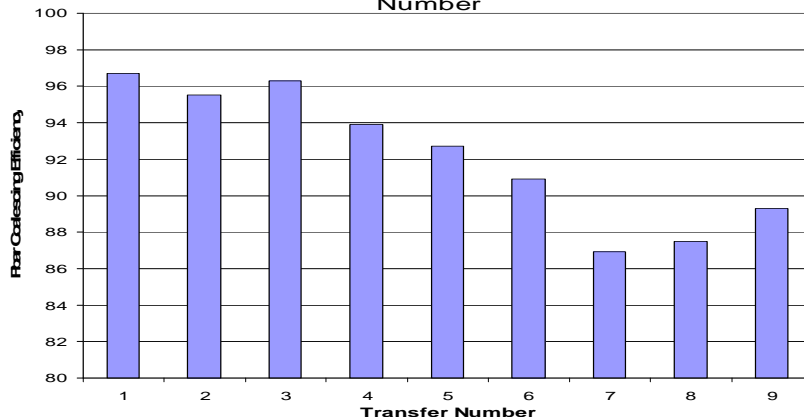


## pbar coalescing scheme in use

Pbar Long. Emit. at 8 GeV and 150 GeV vs. Transfer Number



Average Pbar Coalescing Efficiencies vs. Transfer Number



- Run II upgrade plans call for pbar longitudinal emittance in the Tevatron at collision to be  $<2.5$  eVs/bunch. The existing pbar coalescing scheme in use in MI gives rise to 100-140% emittance growth at 150 GeV compared with 8 GeV values and a decrease in bunch intensity by about 5-10%. The large emittance has direct negative impact on ppbar luminosity in the Tevatron

- Up to about 7% through hourglass factor at interaction
- $> 5\%$  effect through pbar intensity
- $\sim 12\%$  beam loss due to longitudinal shaving during acceleration in the Tev.

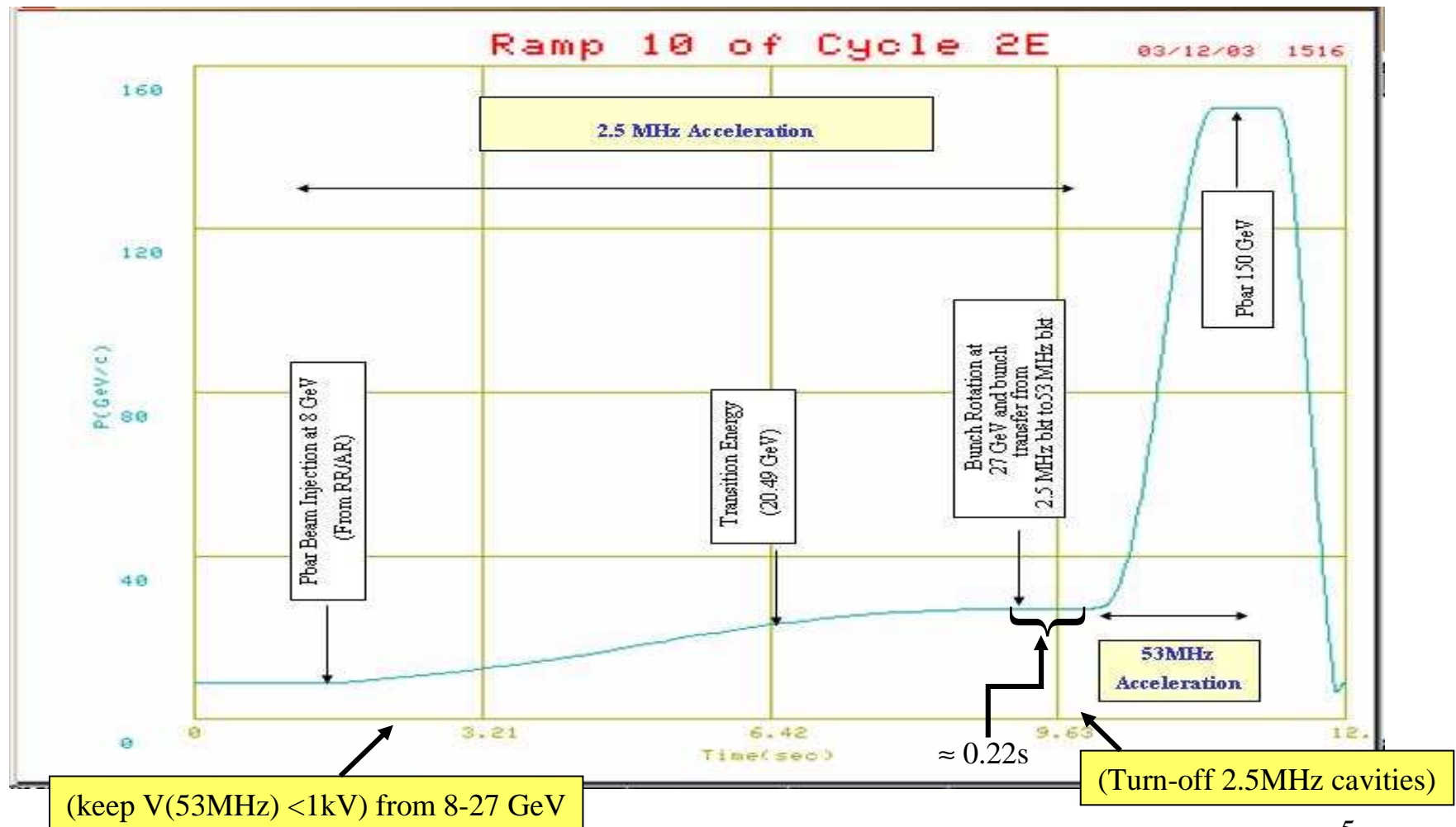
The present coalescing scheme in MI for pbars from the Recycler (expected long. emit. at 8 GeV is  $\sim 1.5$  eVs), will give rise to emittance  $> 3$  eVs at 150 GeV. The impact will be even larger.



# What is the Acceleration Scheme?



It is simple! Do harmonic transfer from  $h=28 \rightarrow h=588$  above MI transition energy  
(“Fermilab Recycler Ring Technical Design Report” Fermilab-TM-1991, Nov. 1996)



Chandra Bhat



# Project Goal



- From the proposed acceleration scheme we expect at 150GeV
  - 53MHz bunch separation = 397 ns,
  - Longitudinal emittance growth <50%
  - No beam loss.
  - Time gap between consecutive pbar transfer to Tevatron be 60 sec with a total of nine transfers to the Tevatron
- Assumed initial beam parameters:
  - Four 2.5MHz pbar bunches separated by 397ns at injection for every MI acceleration cycle.
  - The longitudinal emittance  $\approx 0.8 - 2.2$  eVs
  - Bunch intensities  $\approx 50-170E9$  pbars/bunch

@ In mid-2002, the goal for max. pbar intensity/bunch was set to 60E9 with 397 nsec bunch spacing . Over the last one year the Run II upgrade project evolved and a new intensity goal of 170E9 pbar/bunch is set.



## Beams Division Review of the Project



- A technical review was held in October 2003 to evaluate the project status, better understand the project scope and prioritize accordingly. The committee was convinced that this project can **potentially provide up-to 20% increase in Tevatron luminosity**. The committee urged the project management to set the project's priority similar to “slip-stacking”. It further recommended that attempts should be made to get **the scheme operational by spring of 2004**.



# Beam Dynamics Simulations (ESME)



- **Standard Transition Phase-jump**
- **Beam Properties:**
  - 60E9-170E9/bunch
  - Long. Emit. : 0.8-2.8eVs
- **One Bunch Scenario**
  - Including space-charge effects and MI broad-band impedance
- **Four Bunches with Feed-back & Feed-forward Beam-loading compensation:**
  - 2.5MHz BLC
  - 53MHz BLC
  - Including effect of 53MHz rf system during 2.5MHz acceleration

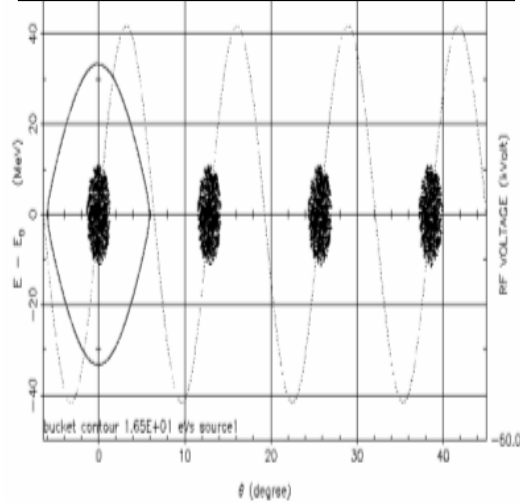




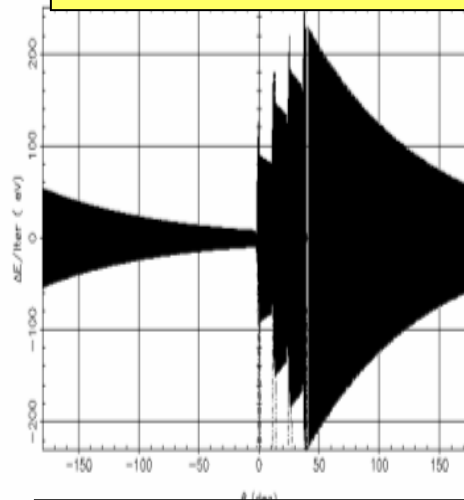
# Simulation with 53MHz Beam-loading Compensation: 170E9@1.5eVs



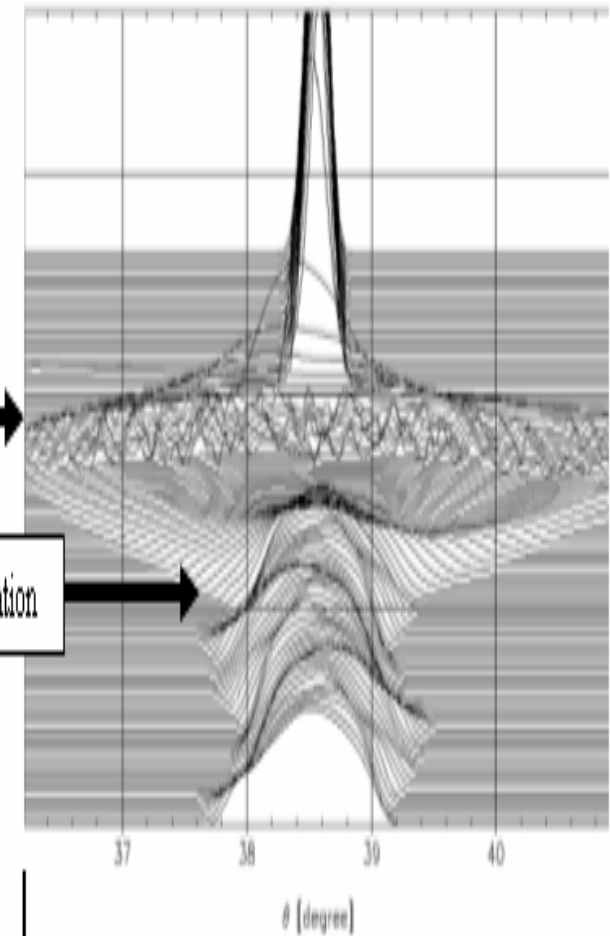
Phase-space dist. @8 GeV



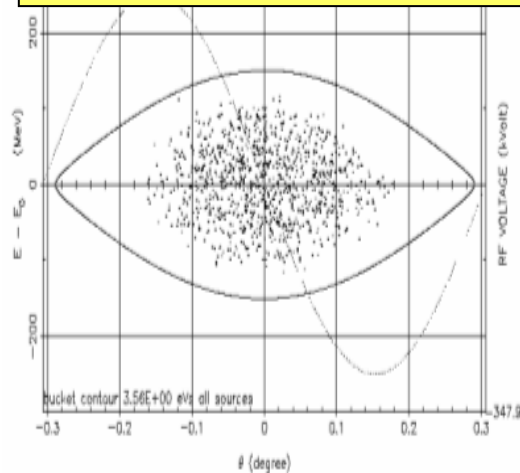
Beam induced voltage



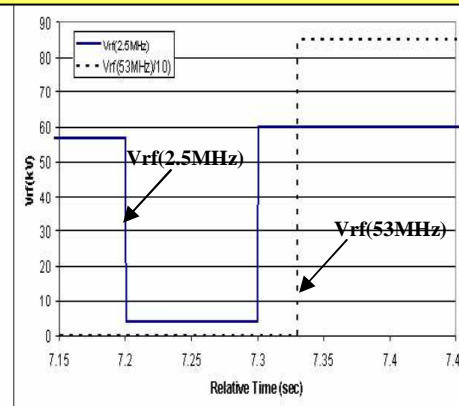
Mountain-range during 27GeV bunch rotation



Phase-space dist. @150GeV



RF Manipulations at 27GeV:  
Two rotation Scenario



2<sup>nd</sup> rotation

1<sup>st</sup> rotation

A maximum of 30% emittance dilution



# HLRF Specifications



- **Beam Loading Compensation**
    - 2.5MHz Feed-back (FB) factor of 5
    - 2.5MHz Feed-forward (FF) factor of 10
    - 53MHz Feed-back factor of 5
    - 53MHz Feed-forward factor of 10
  - 53MHz rf voltage  $< 400\text{V}$  during the 2.5MHz acceleration from 8-27 GeV and bunch rotation
- } HLRF group has implemented BLC but needs to be optimized



# LLRF Specifications & hardware requirements



- For 2.5MHz Acceleration (8-27 GeV)
  - RPOS detector and loop closed better than 1mm ???
  - Phase detector for acceleration phase control and transition phase jump
- For 53MHz Acceleration (27-150 GeV):  
Existing system is adequate

I:HP612 for RPOS  
&  
MI Longitudinal  
kicker as Phase  
detector



# Status of HLRF and some recent improvements ☺



- **HLRF- 2.5MHz and 53MHz FB &FF Beam loading compensation**
  - Made available for 2.5MHz acceleration studies after the October 2003 shutdown
- **Recent Improvements:** A new 49 MHz FFUTR (Feed Forward Up the Ramp) system has been implemented.
  - This helped immensely to the beam-loading compensation. With FF on & station off we see  $\approx 14\text{dB}$  reduction in fundamental, which corresponds to a  $V_{\text{rf}}(53\text{MHz}) \approx 30\text{V}$  with about  $60\text{E}9$  p/bunch
  - Capability to turn-off 53MHz system during 8 GeV 2.5MHz bunch beam capture and bunch rotation at 27 GeV.

☺ Many of these improvements were made as a part of Run II Upgrade Plan for “slip-stacking”, “coalescing at 150 GeV -proton and antiproton beam to Tevatron” and “Beam transfer to the Recycler at 8 GeV”



# Beam Studies



## Beam acceleration

- Before Oct. 2003 shut-down (with FB BLC and no FF BLC)
- After the shut-down (with BLC on, but not optimized)

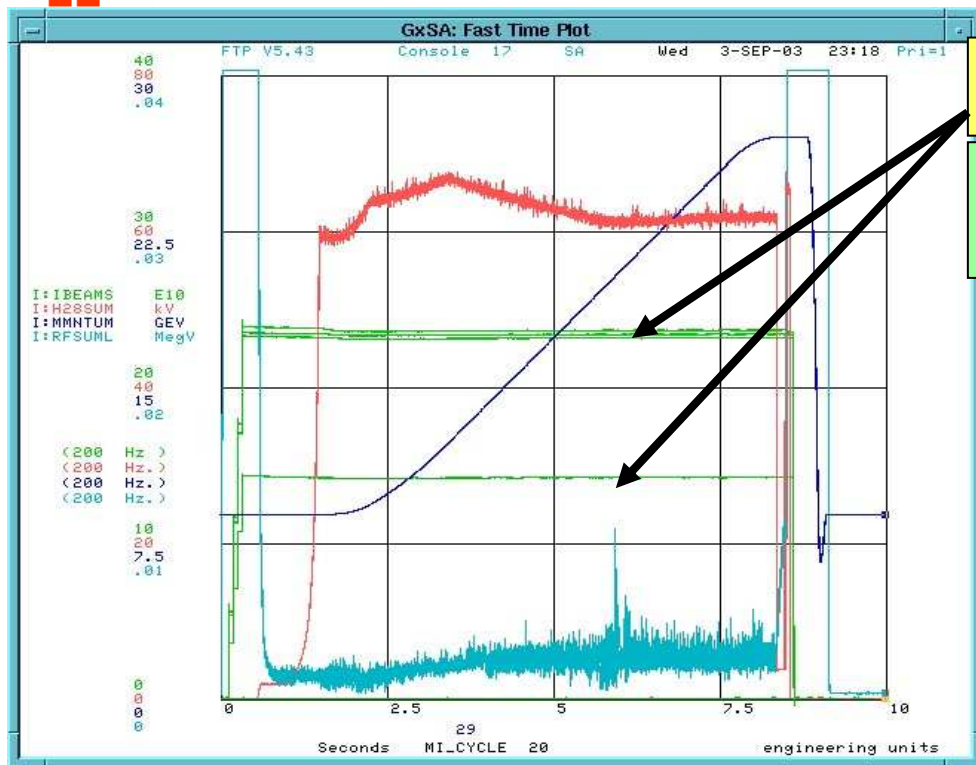
## Beam properties and RF parameters used for beam studies

- Proton Beam
  - Four-bunches 2.5MHz bunches at 8 GeV
  - $20E9$ - $170E9$  protons/bunch
  - Long. emit. : 0.8eVs -2.0eVs
- **Mode of harmonic transfer:** Two rotation Scenario♣
- **HLRF:**
  - $V_{rf}(2.5\text{MHz})=2\text{-}60\text{kV}$  and  $V_{rf}(53\text{MHz})$  rf was para-phase down to about 1kV (?)
  - $V_{rf}(53\text{MHz})= 1\text{kV-}4\text{MV}$
- **Status of Beam Loading Compensation**
  - 2.5MHz and 53MHz Feed-back as well as Feed Forward beam loading compensation were on, but, not optimized
- **LLRF**
  - With 2.5MHz RPOS loop and Phase control

♣ We have also investigated four rotation scenario

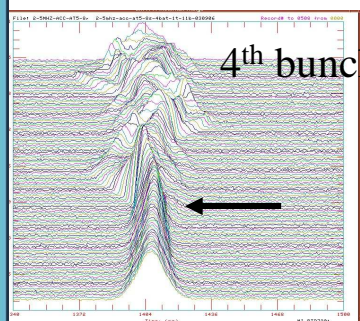


# Status before Oct. 03 shutdown



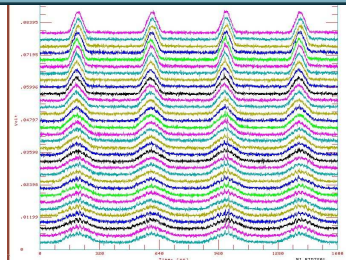
• 100% Transmission from 8 -27 GeV

• Reasonably good Transition crossing for the 2nd bunch, not good for 4<sup>th</sup> bunch

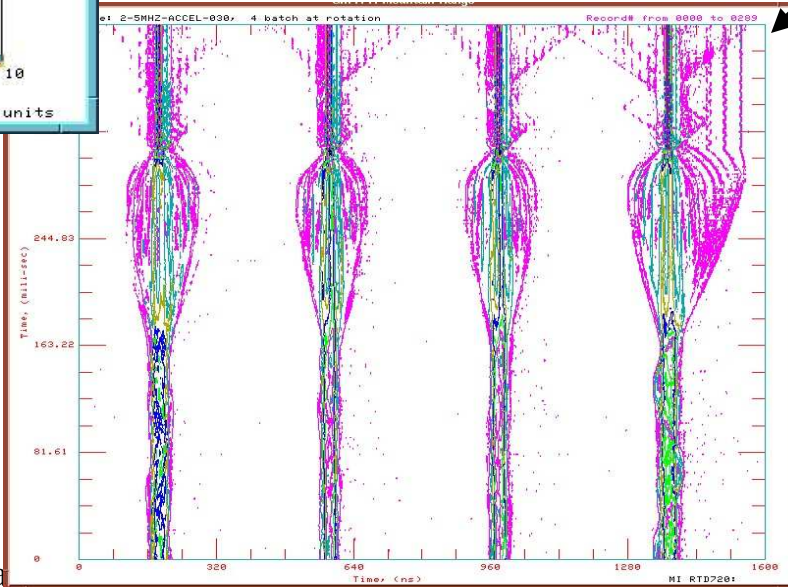
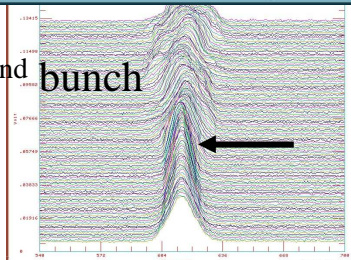


• Harmonic transfer

8GeV  
Beam



2<sup>nd</sup> bunch



## Conclusions:

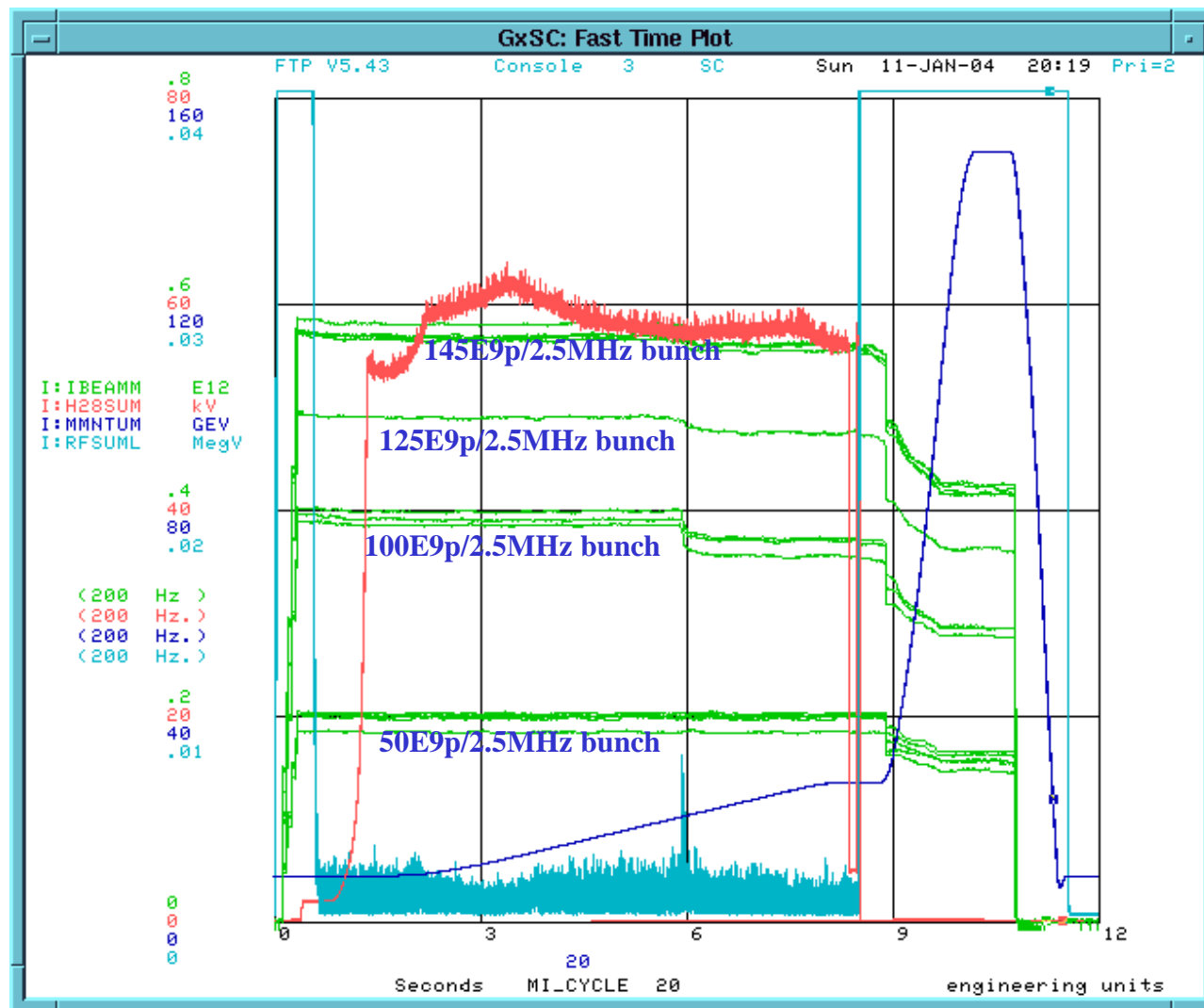
≈45% emit. growth (max) from 8 to 27GeV with ≈10% beam in satellite





# Present Status

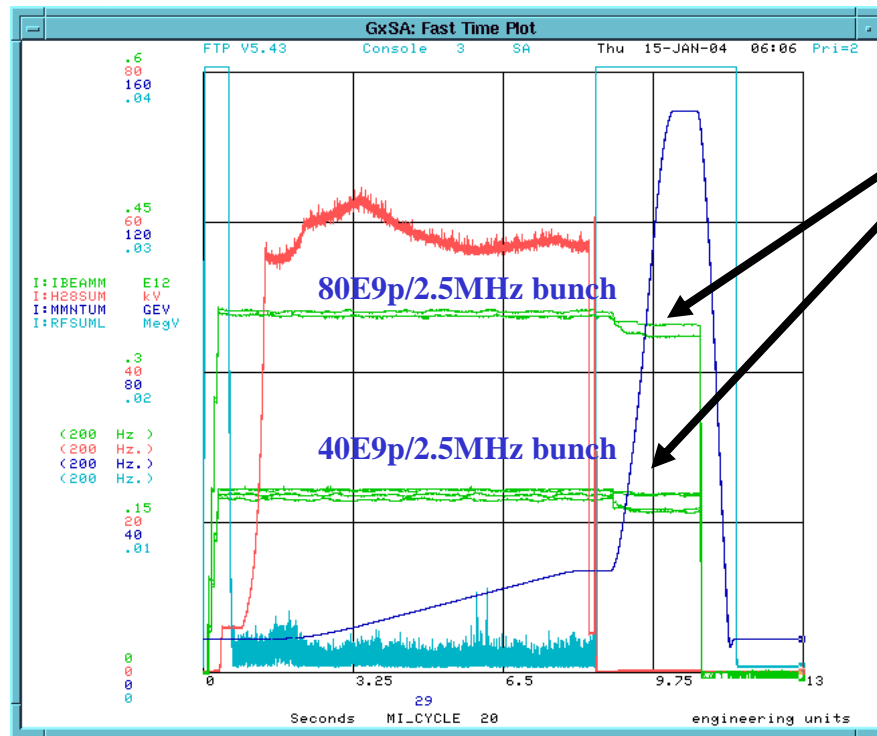
## Beam acceleration to 150 GeV open-loop between 27 to 150 GeV



Chandra Bhat

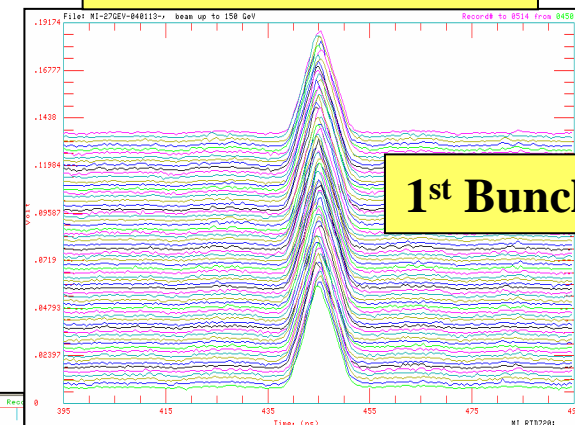


# 8-150 GeV Acceleration

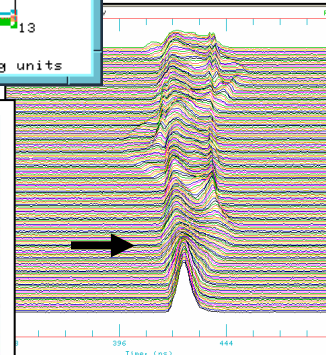
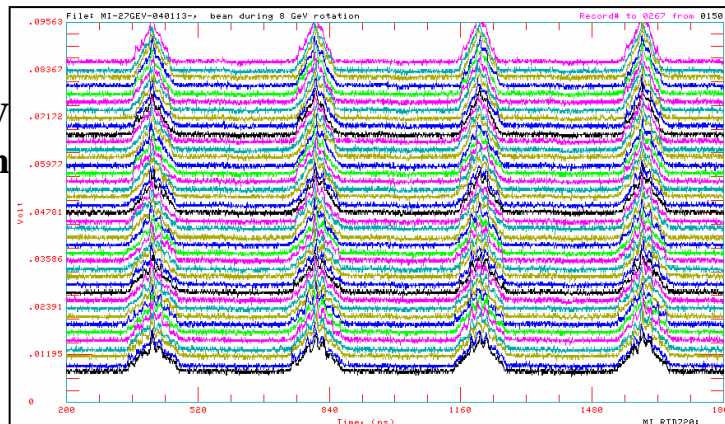


• ~100% beam transmission

**Bunches at 150 GeV**

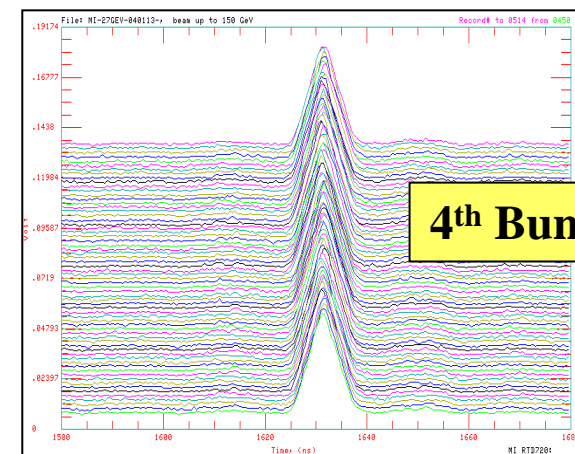


**8GeV Beam**



Transition  
Crossing of 1st  
bunch

**4th Bunch**



Chandra Bhat

10





# Milestones: Beam Studies



## Studies with Protons:

1	<b>2.5MHz acceleration from 8- 27 GeV and capture in 53MHz buckets</b> (cycle time $\approx$ 9 sec)	- 2.5MHz bunches prepared at 8 GeV - 20-60E9p/bunch - $\epsilon_l = 0.8$ -2.2 eVs	<b>Achieved</b> Slow acceleration with 2.5MHz RPOS loop closed & Phase-feedback.(before Oct.03 BD review) no BLC $\Delta\epsilon(\text{max}) \sim 45\%$ Trans. Eff. $\sim 100\%$
2	<b>2.5MHz acceleration from 8-27 GeV and 53MHz acceleration from 27 GeV to 150 GeV</b> (cycle time $< 13$ sec)	30E9 p/bunch $\sim 100\%$ efficiency 145E9 p/bunch $\sim 75\%$ efficiency	<b>Achieved</b> With BLC on Do not have data on emittance

## Future Plans

3	Same as step 2	60-170E9p/bunch	Tune BLC, Transition crossing & Bunch rotation
---	----------------	-----------------	--

## Studies with pbars:

4	<b>Pbar acceleration from 8-150 GeV, Transfer to Tevatron</b> (cycle time $< 13$ sec)	Use the 2.5MHz pbars bunches from Accumulator/RR	-2.5MHz bunch transfer to MI is Done. -Pbar accel. will be after completion of step 3
---	--	--	--



# Issues



## Reliability

- Transition crossing:
  - There are some intensity dependent effects which arise from beamloading of 2.5MHz and 53MHz rf systems. Preliminary results with BLC is very encouraging.
- How well do we keep  $V_{rf}(53\text{MHz})$  low reliably during 8-27 GeV acceleration? – A special vector control box is being developed by RF group to para-phase.
- 2.5MHz rf cavity heating:
  - During our beam studies the cavity performance has been closely monitored. We observed a considerable voltage dropping and phase shift due to cavity heating during studies for extended period. Precautions have been taken to limit the power put into the 2.5MHz cavities. This limits us to 2-3 hour shifts per study period.
  - Operation require only 9 transfer to Tevatron. Cavities do not show any noticeable effect for nine consecutive pbar transfer if the cycles are separated by 60 sec. A procedure will be developed to this effect.



## Future Study Plans

**1 Shift = 2 hours, One study cycle/ 120~180 sec, Cycle time  $\approx$  13sec**

- Tune BCL (4 shifts)
- Optimize transition crossing and para-phase and rotation at 27 GeV(4 shifts)
- Optimize the RPOS loop control from 27-150 GeV(4-shifts)
- High Intensity studies (3 shifts)

**Total of about 15 shifts required**

- Work on an application program to measure the long. emittance at various stages of acceleration. (SBD?)

**With contingency we may need ~ 20 shifts. This corresponds to about 50 hours of beam time with an impact of 7-10% on the time-line.**

**Make it operational by spring 2004**



## Summary



- Have investigated a new pbar acceleration scheme in the MI for collider operation. This scheme is expected to give  $\Delta\epsilon_l < 50\%$  from **8-150GeV** with no beam loss.
- The scheme involves the use of
  - 2.5MHz rf system for 8-27 GeV acceleration
  - Bunch rotation in 2.5MHz rf bucket at 27 GeV
  - 53MHz rf system for the 27-150GeV acceleration
- We have carried out
  - Beam dynamics simulations: ESME, for  $\epsilon_l=0.8-2.8\text{eVs}$ , beam intensities = 60-170E9pbars/bunch. Space-charge and BLC effects are modeled.
  - Beam studies:  $\epsilon_l=0.8-2\text{eVs}$ , beam intensities = 20-145E9p/bunch for four bunches acceleration with BLC on.



## Summary (cont.)



- Simulations done with BLC and  $V_{rf}(53\text{MHz}) \sim 600\text{V}$  predict
  - up to about 35% longitudinal emittance growth for bunches with  $\epsilon_l = 0.8\text{--}2.8\text{eVs}$  and  $170\text{E9}$  pbars/bunch for the case of four bunch acceleration from 8-150 GeV.
- **Beam Studies with Protons: Acceleration from 8-150 GeV**
  - **Prior to October 2003 shutdown (with partial 2.5MHz BLC and no 53MHz BLC)**
    - ▶ Transmission efficiency  $\sim 100\%$  from 8-27 GeV
    - ▶  $\approx 45\%$  overall emittance growth for  $50\text{E9p/bunch}$  for  $\epsilon_l = 0.8\text{--}2.0\text{ eVs}$
    - ▶  $\approx 90\%$  beam in central bunch and  $\approx 10\%$  in satellites
  - **Present Status (with partially commissioned BLC)**
    - ▶ Intensity of  $20\text{--}145\text{E9p/bunch}$  and  $\epsilon_l = 0.8\text{--}2.0\text{ eVs}$
    - ▶ Transmission efficiency  $\sim 100\%$  from 8-150 GeV for beam up to  $80\text{E9/bunch}$

We do not see any showstoppers!



## Status of LLRF Control



- Beam transfer from the Booster and Accumulator
- Beam harmonic transfer from H588 to H28
- Bucket alignment between H588, H28 and H1 harmonics
- RF vector amplitude control for 2.5 MHz via curve generators and messages
- RF vector amplitude control for 53 MHz via A/B group counterphasing messages

### ► May 9<sup>th</sup>, 2003

- **Feedforward acceleration phase angle real time calculation based on the MDAT distributed MI ramp momentum data**
- **2.5 MHz acceleration and deceleration transition crossing based on RF frequency**

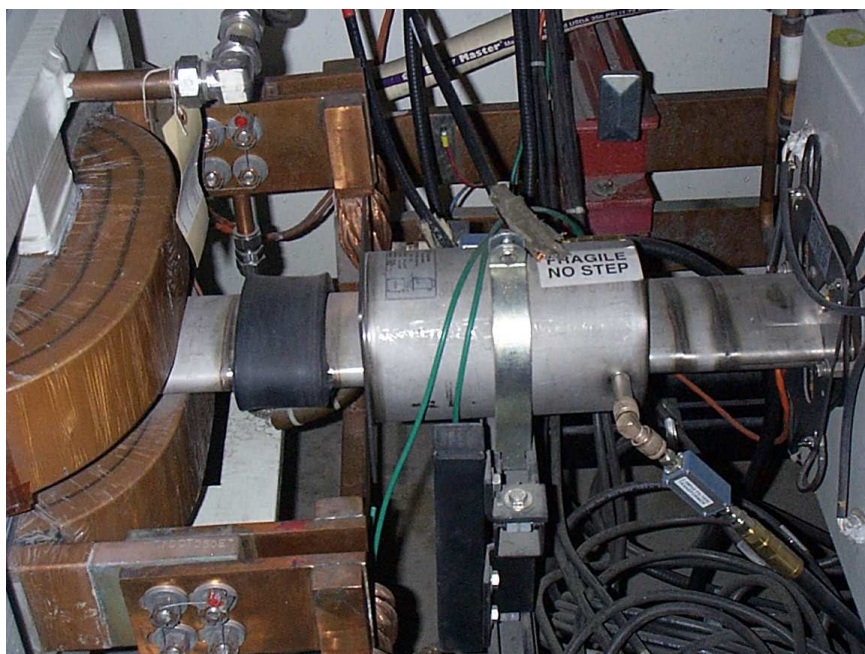
### ► July 16<sup>th</sup>, 2003

- **Beam detection and processing for 2.5 MHz Radial Position and a Frequency Phase Lock Loop (Fpll) via the VXI DSR module**
- 2.5 MHz Beam Radial Position feedback via the ROFF curve and 2.5 MHz Fpll
- Beam harmonic transfer from H28 to H588

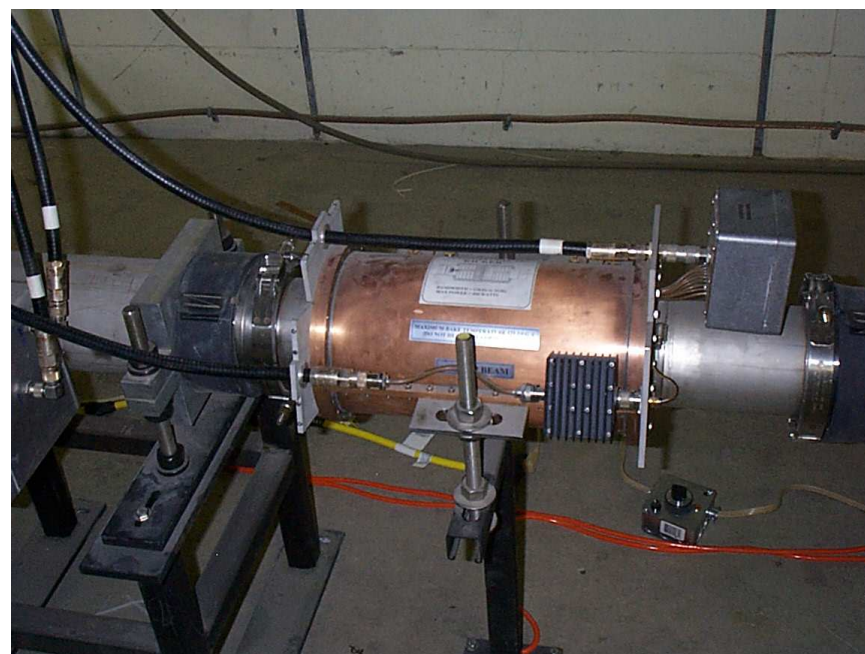




## LLRF detectors for 2.5MHz Acceleration



2.5MHz RPOS detector  
at MI612 location



MI Longitudinal kicker as  
2.5MHz Phase detector

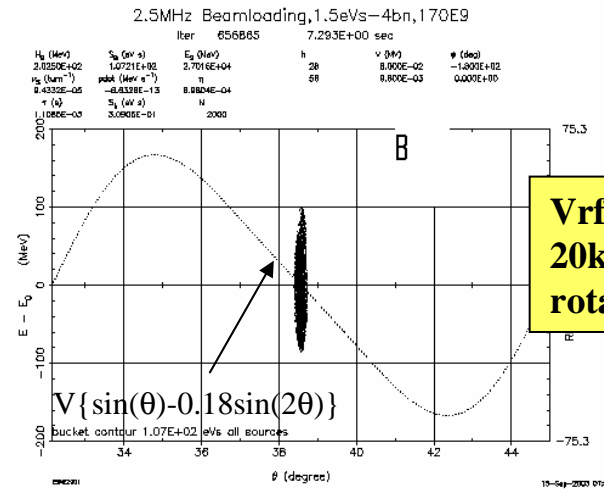
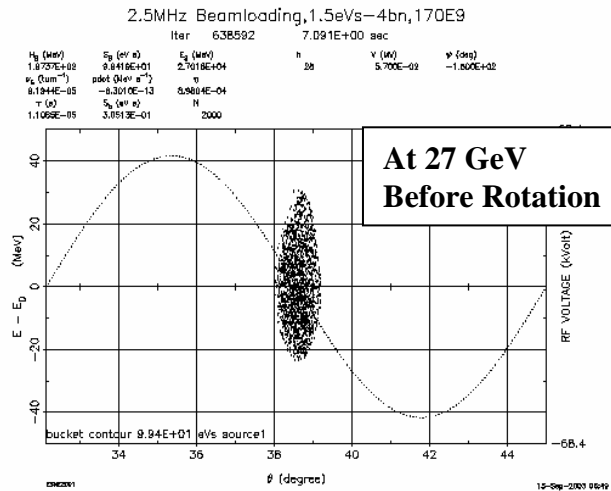


# ESME: Four Rotation Scenario



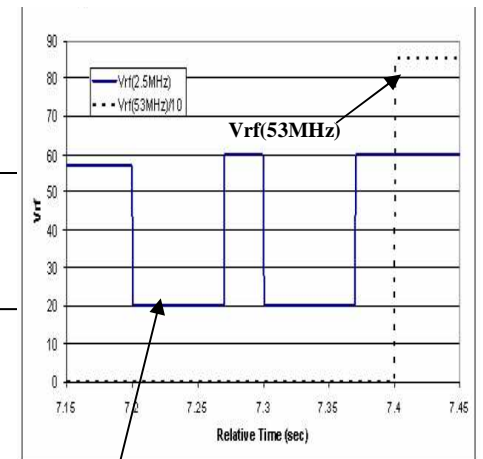
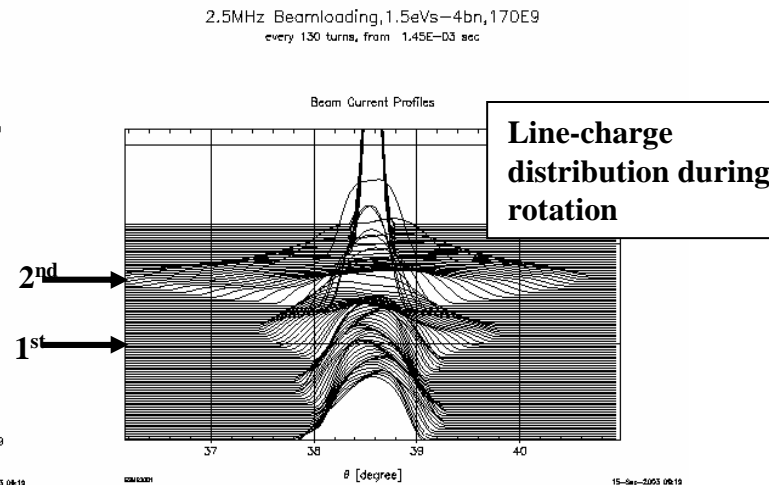
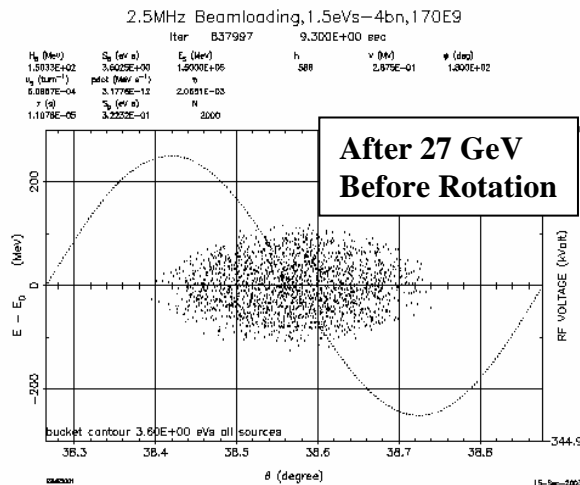
To minimize the effect of  $V_{rf}(53\text{MHz})$  during harmonic transfer

F



$V_{rf}(2.5\text{MHz}) \approx 15-20\text{kV}$  during the rotations

RF Manipulations at 27 GeV:  
Four Rotation Scenario



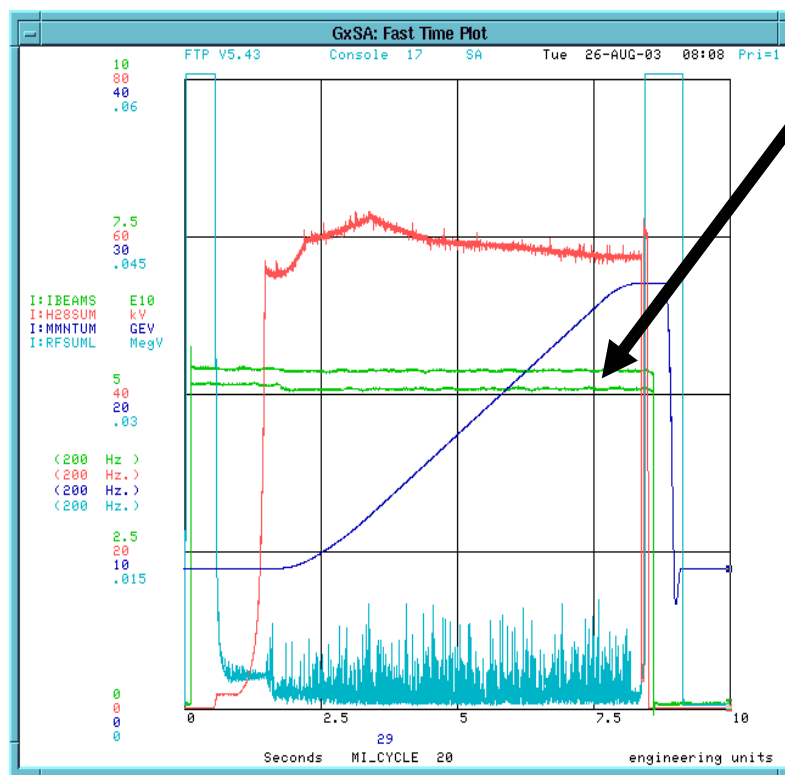
$V_{rf}(2.5\text{MHz})$

Conclusions:  $<10\%$  emittance growth from 8 -150 GeV with no particle loss



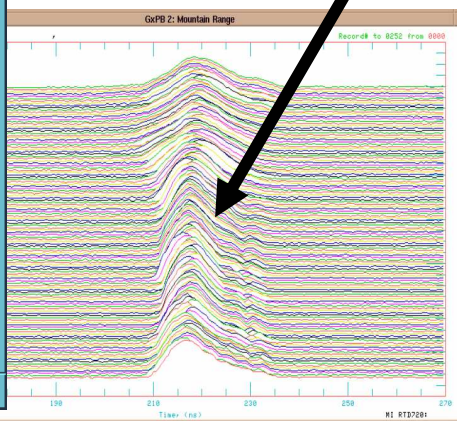


# One Bunch Acceleration

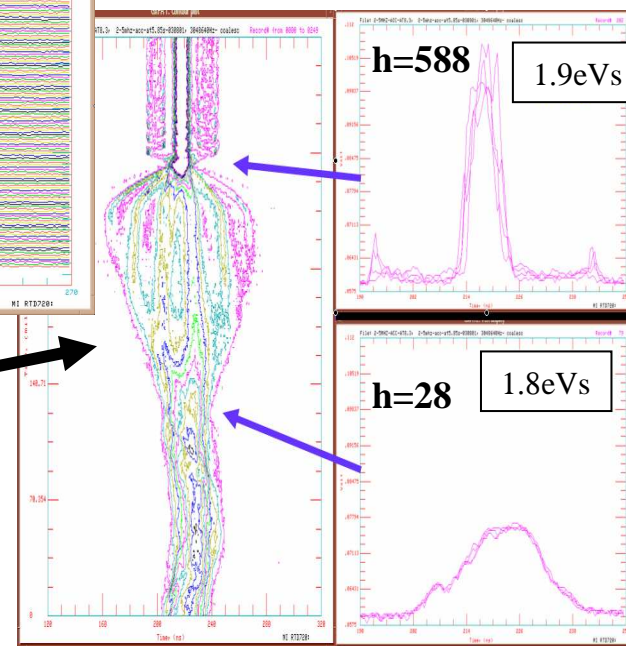


• 100% Transmission from 8 -27 GeV

• Reasonably good Transition crossing



• Harmonic transfer



## Conclusions:

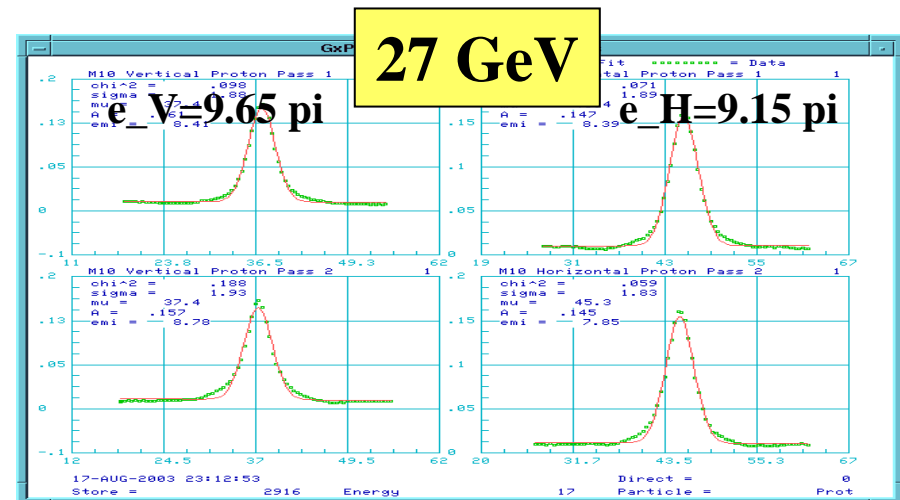
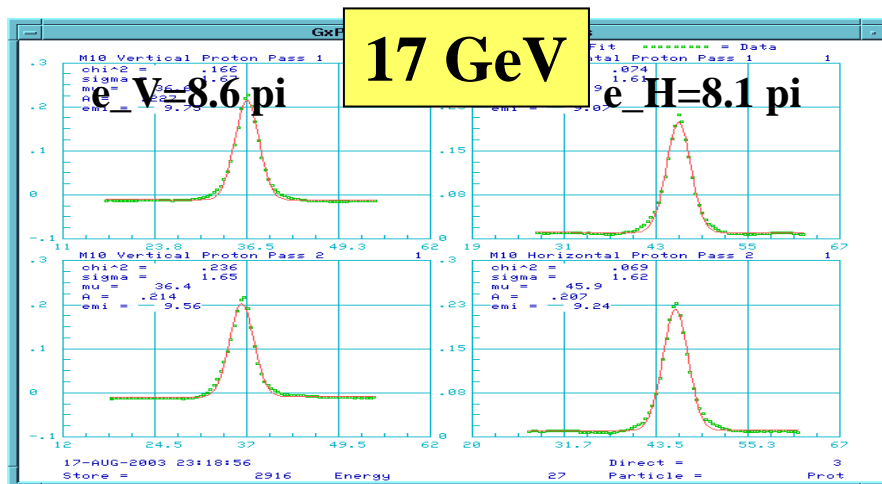
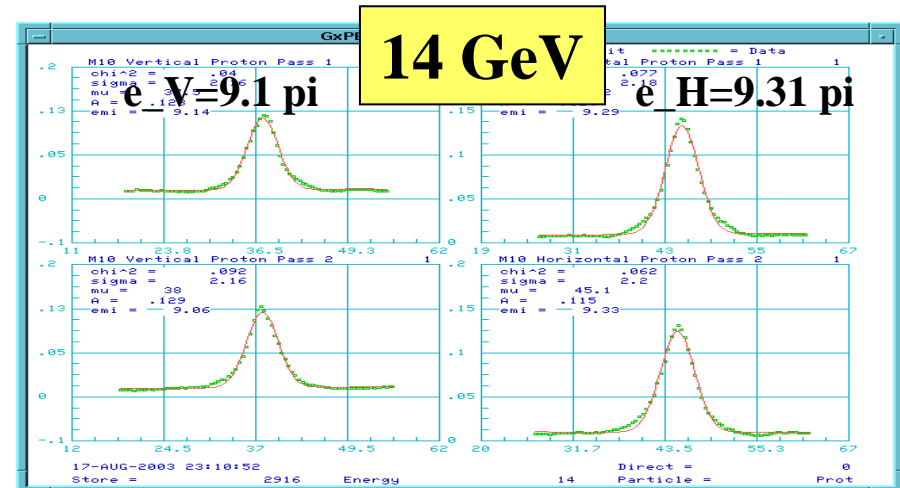
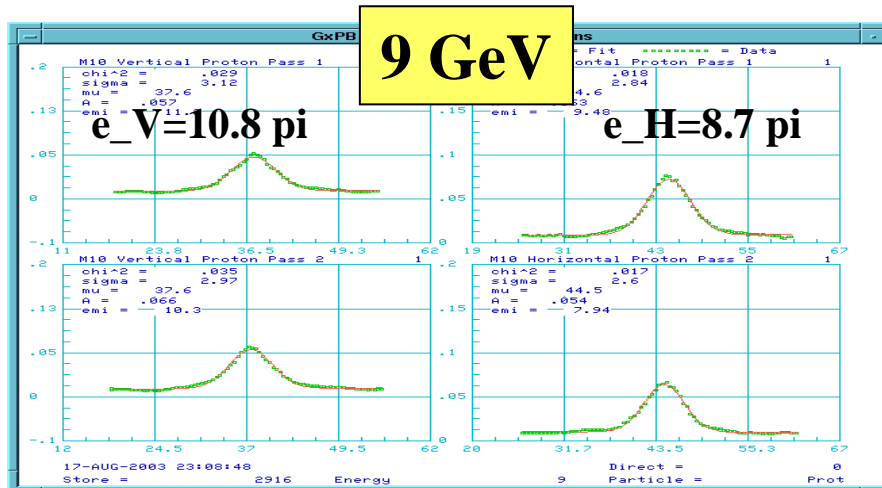
≈30% emittance growth from 8-27 GeV  
with ≈5% beam in satellite

Chandra Bhat



# 2.5MHz Acceleration :

Transverse Emittance Measurements different cycles



Conclusions: Within the measuremental errors there is no transverse emittance growth

Chandra Dhat